RESEARCH ON BLUFF BODY VORTEX WAKES

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PROJECT ABSTRACT

Long-Term Goals

This combined experimental-computational research addresses the problem of flow-induced forces on vortex-shedding bluff bodies. The long term goals are:

1. To improve understanding of the relation between the unsteady forces and vorticity histories in the near wake.

2. To use new results and insights to assess existing models for flow-induced unsteady forces and to seek alternative models.

Objectives

Immediate objectives are to obtain experimental and computational descriptions of velocity and vorticity fields in the near wakes of vortex-shedding bodies and the corresponding forces on the bodies.

Approach

The basic approach is to obtain measurements in correlated laboratory experiments and numerical simulations of flows past bluff bodies, especially circular cylinders. Laboratory measurements include flow visualization and digital particle image velocimetry (DPIV). Numerical simulations are based on vortex methods. Interpretation of relations between measured velocity/vorticity fields and body forces is sought through the generalized Biot-Savart law. The role of Reynolds number, effects of three dimensionality, and effects of body motion are investigated. Relations to the *mean* near-wake flow and mean force (drag) are also studied, for their basic technological importance and also for insights into the unsteady motion.

Tasks Completed/Technical Accomplishments

This is a new project, but in the meantime we have accomplished the following:

A small experimental flow facility has been assembled for investigating the effect of three dimensionality. The fluid (water based) is ferromagnetic and the test section is located in the magnetic field of an existing large electromagnet in our laboratory. The magnetic field can be parallel or normal to the cylinder axis. The motivating idea is that the magnetic field interacts with and modifies the velocity/vorticity fields in the near wake. This experiment is related to a previously reported one in which effects on spanwise (ie "three dimensional") velocities and on body-force history was achieved in gravity-stratified flow.

A study (Roshko, 1994) on the mean flow in near wakes of bluff bodies has been completed. It addresses the "closure" or "reattachment" region on the downstream side of the near wake and complements an earlier study and paper (Roshko, 1993). Denoting the downstream distance from the cylinder base to closure point by l and the transverse width of the near wake by W, an interesting result of the model is that the aspect ratio of a near wake with splitter plate is independent of the cylinder cross sectional shape and has a value $l/W = 3$. (The length l/d, does depend on the cross sectional shape.) For vortex-shedding cylinders both l/W and l/d are much smaller but to model them will be more difficult.

We started a feasibility study using real-time feedback control systems to reduce the flow-induced oscillation of a cylindrical pendulum. In our experiments, the pendulum was pivoted from a base plate in a crossflow. The base plate was mounted on a computer controlled traverse. Our feedback system controller is designed to minimize the angle between the pendulum and vertical by moving the base. The control algorithm is PID controller with an offset to accomodate for low torque of the motor at low voltage. We plan to study the error (offset signal) in terms of dynamical system parameter. These studies will be performed for the conditions of natural or forced by means of an upstream circular cylinders.

We continued to investigate the impact of the addition of a streamwise component of vorticity to a boundary layer at the point of separation from an axisymmetric bluff body. This effect was achieved by having a rotating ribbon at the point of separation (see last year's report for details). Initial studies indicated a mere 25% drag reduction at certain Re number range. However, due to some complex mechanical problems in the initial set of experiments, we would like to repeat these experiments. Hot wire studies of the initial region of the shear layer indicates some dramatic change in the growth and evolution of the mixing layer. We plan to correlate these changes to the base pressure distribution and to develop a physical model for the possible drag reduction observations.

A sequence of two-dimensional numerical simulations of flow past a cylinder undergoing various oscillatory motions—rotation, cross-flow, and free-stream—were performed using our high resolution, viscous vortex method. The results are being used to study the interactions of body motions and near wake vortices and their effect on body forces. The high resolution method has recently been implemented on the new CRAY T3D parallel computer at JPL. Preliminary test runs are underway.

AF-AFOSR-0213786

Results

This is a new start beginning in 1994.

Impact for Science or Systems Applications

Relationship to Other Programs or Projects

Enclosure (1)

PUBLICATIONS FROM ONR SPONSORED WORK – FY93/FY94
ANATOL ROSHKO

94-P Koumoutsakos, P., Leonard, A., and Pepin, F. 1994 "Boundary conditions for viscous vortex methods", *J. Comput. Phys.* **113**, 52–61.

Salmon, J.K., Warren, M.S., and Winckelmans, G.S. 1994 "Fast parallel tree codes for gravitational and fluid dynamical N-body problems", *Int. J. Supercomputer Applications* **8**, 129–142.

Cortelezzi, L., Leonard, A., and Doyle, J.C. 1994 "An example of active circulation control of the unsteady separated flow past a semi-infinite plate". *J. Fluid Mech.* **260**, 127–154.

93-P Leonard, A. and Koumoutsakos, P. 1993 "High resolution vortex simulation of bluff body flows", *J. Wind Eng. and Indust. Aero.* **46** and **47**, 315–325.

Winckelmans, G.S. and Leonard, A. 1993 "Contributions to vortex particle methods for the computation of three-dimensional incompressible unsteady flows", *J. Comput. Phys.* **109**, 247–273.

94-PS Koumoutsakos, P. and Leonard, A. "High resolution simulations of the flow around an impulsively started cylinder using vortex methods". Accepted for publication, *J. Fluid Mech.*

Roshko, A. "Free shear layers, base pressure and bluff-body drag". To appear in *Proceedings of the Symposium on Developments in Fluid Dynamics and Aerospace Engineering*, Bangalore, India, December 9-10, 1993.

94-P1 Lewis, C.G. and Gharib, M. "The Effect of Axial Motion on the Wake of a Cylinder in Steady Uniform Flow". In preparation.

93-C Gharib, M., Lewis, C., and Lisoski, D. (1993) "The Effect of Axial Motion on the Wake of Circular Cylinders: Simulation of Yawed Cylinder Wakes". Fourth Workshop on the ONR Accelerated Research Initiative *Vortex Shedding and Vortex Wakes: Dynamics, Instabilities and Modifications*, Arizona State University, Tempe, December 8–10, 1993.

Henderson, R.D., Hammache, M., Gharib, M., and Karniadakis, G.E. "Vorticity Distribution in the Wake of Bluff Bodies". 46th Annual Meeting of the Division of Fluid Dynamics of the American Physical Society, Albuquerque, New Mexico, November 21–23, 1993.

Koumoutsakos, P. and Leonard, A. "The No-Slip Boundary Condition for Viscous Vortex Methods". 46th Annual Meeting of the Division of Fluid Dynamics of the American Physical Society, Albuquerque, New Mexico, November 21–23, 1993.

Roshko, A., Cardell, G., and Lisoski, D. "Interactions between the Vortices and the Free Shear Layers in Bluff-Body Wakes". Fourth Workshop on the ONR Accelerated Research Initiative *Vortex Shedding and Vortex Wakes: Dynamics, Instabilities and Modifications*, Arizona State University, Tempe, December 8-10, 1993.

94-IC Leonard, A. "Numerical Simulation of Turbulent Flows". ICASE/NASA Langley Short Course on Turbulent Flow Modeling and Prediction, Hampton, Virginia, March 14-18, 1994.

Leonard, A. "Vortex Methods for Three-Dimensional Separated Flows". 14th International Conference on Numerical Methods in Fluid Dynamics, Bangalore, India, July 11-14, 1994.

Roshko, A., "What is the Turbulence Problem?" and "Shear Layers, Base Pressure and Bluff-Body Drag." Invited speaker for two seminars at the Luigi Crocco Colloquium, Princeton University, New Jersey, April 21-22, 1994.

Roshko, A., "What is the Turbulence Problem?" Invited speaker for two special seminars—the first one was held at the Los Alamos National Laboratory, New Mexico, July 14-15, 1994 and the second one was held at the Sandia National Laboratory, Albuquerque, New Mexico, July 18, 1994.

93-IC Roshko, A., "Instability and Turbulence in Free Shear Flows." Invited speaker at the Distinguished Fluid Dynamics Lecture, Univ. of Illinois at Urbana-Champaign, October 8, 1993.

Roshko, A., "Free shear layers, base pressure and bluff-body drag." Invited speaker at the Symposium on Developments in Fluid Dynamics and Aerospace Engineering, Bangalore, India, December 9-10, 1993.

OFFICE OF NAVAL RESEARCH
PUBLICATIONS/PATENTS/PRESENTATIONS/HONORS REPORT
1 October 1993 through 30 September 1994

R&T Number: 321g008---06
Contract/Grant Number: N00014-94-1-0793
Contract/Grant Title: Research on Bluff-Body Vortex Wakes
Principal Investigator: Anatol Roshko
Mailing Address: Aeronautics, Mail Code 105-50, CALTECH, Pasadena, CA 91125
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a. Number of Papers Submitted to Refereed Journal but not yet published: 2

b. Number of Papers Published in Refereed Journals: 5 (list attached)

c. Number of Books or Chapters Submitted but not yet Published: 0

d. Number of Books or Chapters Published: 0 (list attached)

e. Number of Printed Technical Reports & Non-Refereed Papers: 1
(list attached)

f. Number of Patents Filed: 0

g. Number of Patents Granted: 0 (list attached)

h. Number of Invited Presentations at Workshops or Prof. Society Meetings: 8

i. Number of Presentations at Workshops or Prof. Society Meetings: 4

j. Honors/Awards/Prizes for Contract/Grant Employees:
(list attached, this might include Scientific Soc. Awards/
Offices, Promotions/Faculty Award/Offices, etc.)

k. Total number of Graduate Students and Post-Docs Supported at least 25% this year on this contract/grant:

Grad Students 2 and Post-Docs ___ including
Grad Student Female ___ and Post-Docs Female ___
Grad Student Minority ___ and Post-Doc Minority ___

Several of the above categories are inappropriate for most efforts performed under higher category funding. Complete only those items you feel are appropriate. In any case please list all reports and papers.

Enclosure(3)

LIST OF PUBLICATIONS/PATENTS/PRESENTATIONS/HONORS

b. Papers Published in Refereed Journals:

Cortelezzi, L., Leonard, A., and Doyle, J.C. 1994 "An example of active circulation control of the unsteady separated flow past a semi-infinite plate". *J. Fluid Mech.* **260**, 127-154.

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Winckelmans, G.S. and Leonard, A. 1993 "Contributions to vortex particle methods for the computation of three-dimensional incompressible unsteady flows", *J. Comput. Phys.* **109**, 247-273.

d. Books (and sections thereof) Published: None

e. Technical Reports, Non-Refereed Papers:

Roshko, A. (1994) "Free shear layers, base pressure and bluff-body drag". To appear in *Proceedings of the Symposium on Developments in Fluid Dynamics and Aerospace Engineering*, Bangalore, India, December 9-10, 1993.

g. Patents Granted: None

h. Invited Presentations:

Leonard, A. "Numerical Simulation of Turbulent Flows". ICASE/NASA Langley Short Course on Turbulent Flow Modeling and Prediction, Hampton, Virginia, March 14-18, 1994.

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i. Presentations:

Gharib, M., Lewis, C., and Lisoski, D. "The Effect of Axial Motion on the Wake of Circular Cylinders: Simulation of Yawed Cylinder Wakes". Fourth Workshop on the ONR Accelerated Research Initiative *Vortex Shedding and Vortex Wakes: Dynamics, Instabilities and Modifications*, Arizona State University, Tempe, December 8-10, 1993.

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Koumoutsakos, P. and Leonard, A. "The No-Slip Boundary Condition for Viscous Vortex Methods". 46th Annual Meeting of the Division of Fluid Dynamics of the American Physical Society, Albuquerque, New Mexico, November 21-23, 1993.

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j. Honors/Awards/Prizes for Contract/Grant Employees:

Anatol Roshko— Honorary Fellow, Indian Academy of Sciences.